

Supplementary data

Characterisation of Italian bean landraces (*Phaseolus vulgaris* L.) using seed image analysis and texture descriptors

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Supplementary Table 1 - Location of studied Italian traditional bean landraces and main seed characteristics (^a = European trademark PGI obtained or submitted; ^b = Flat seeds; ^c = row drilling; ^d = pocket drilling; W = white coat seed; MC = mono-colored coat seed; BC = bi-colored coat seed).

Cod.	Bean landraces	Harvest year	Seed shape	Seed coat main color	Seed coat secondary color	Seed coat category	Landrace origins	Geographic Area
BaB	Badda Bianca	2011	Circular	White	Cream on half grain	BC	Polizzi Generosa (PA) - Sicily	Sicily
BaN	Badda Niura o Munachedda	2011	Circular	White	Black on half grain	BC	Polizzi Generosa (PA) - Sicily	Sicily
Bia	Bianco	2010	Circular	White		W	Balvano (PZ) - Basilicata	S-Italy
BiP	Bianco di Pigna ^a	2004	Circular	White		W	Pigna (SV) - Liguria	N-Italy
Bil	Billò ^a	2006	Kidney-shape	Cream	Dark red variegation on entire grain	BC	Cuneo (CN) - Piemonte	N-Italy
Bor	Borlotto	2010	Circular	Cream	Brown on entire grain	BC	Garfagnana (LU) - Toscana	C-Italy
BoB	Borlotto Bianco	2004/05	Kidney-shape	Brown		BC	Sarzana (SP) - Liguria	N-Italy
Can	Cannellino	2011	Rectangular	White		W	Sarconi (PZ) - Basilicata	S-Italy
CaP	Cannellino di Pisa	2004	Kidney-shape	White		W	Pisa (PI) - Toscana	C-Italy
CaG	Cannellino di San Ginese	2004	Kidney-shape	White		W	Porcari (LU) - Toscana	C-Italy
CaR	Cannellino Rosso	2011	Kidney-shape	White	Red on entire grain	BC	Sarconi (PZ) - Basilicata	S-Italy
Ciu	Ciuoto sin. Regina sin. Napulitano Vasciu	2011	Circular	Cream	Red on entire grain	BC	Sarconi (PZ) - Basilicata	S-Italy
Cr1	Crucchittu 1	2007	Circular	Violet		MC	S. Piero Patti (ME) - Sicily	Sicily
Cr2	Crucchittu 2	2007	Circular	Violet	Brown on entire grain	BC	Casale Floresta (ME) - Sicily	Sicily
DeC	Della Chiesa	2010	Circular	Cream	Brown on entire grain	BC	Massa Carrara (MS) - Toscana	C-Italy
Fag	Fagiolini di maggrese bianco	2010	Circular	White		W	Balvano (PZ) - Basilicata	S-Italy
Fiu	Fiumara	2007	Circular	Cream		BC	S. Piero Patti (ME) - Sicily; Racchia (ME) - Sicily	Sicily Sicily
Gia	Giallo	2010	Rectangular	Brown		MC	Balvano (PZ) - Basilicata	S-Italy
Gio	Giovanna	2007				BC	Castell'Umberto (ME) - Sicily	Sicily
Lam	Lamon ^a	2006	Kidney-shape	Cream	Violet on entire grain	BC	Belluno (BL) - Veneto	N-Italy
Lar	Lardariello	2010	Circular	Cream	Brown on entire grain	BC	Balvano (PZ) - Basilicata	S-Italy
LaQ	Lardariello Quarantina	2010	Circular	Cream	Brown on entire grain	BC	Balvano (PZ) - Basilicata	S-Italy
Lup	Lupinaro	2004/05/06	Kidney-shape	Cream	Red on entire grain	BC	Sarzana (SP) - Liguria	N-Italy
Ma1	Maruchedda 1	2011	Circular	Cream	Brown on entire grain	BC	Sarconi (PZ) - Basilicata	S-Italy
Ma2	Maruchedda 2	2011	Circular	Cream	Brown on entire grain	BC	Sarconi (PZ) - Basilicata	S-Italy
Mas	Mascherino	2010	Circular	Cream	Black on half grain; Violet on half grain	BC	Pisa (PI) - Toscana Garfagnana (LU) - Toscana	C-Italy C-Italy
Moi	Moitano	2007/08	Kidney-shape	Cream		MC	Randazzo (CT) - Sicily	Sicily
Muc	Munachedda	2011	Circular	White	Cream on half grain	BC	Sarconi (PZ) - Basilicata	S-Italy
MuN	Munachedda Nera	2011	Circular	Black	White on one-third grain	BC	Sarconi (PZ) - Basilicata	S-Italy
Mus	Mussuniuru	2007	Circular	White	Black/Brown around hilum	BC	S. Piero Patti (ME) - Sicily; Racchuia Sinagna c/da Bosco (ME) - Sicily	Sicily Sicily
Nas	Nasieddu	2011	Circular	White	Black around hilum	BC	Sarconi (PZ) - Basilicata	S-Italy
NaN	Nasieddu Nero	2011	Kidney-shape	White	Black around hilum	BC	Sarconi (PZ) - Basilicata	S-Italy
NaR	Nasieddu Rosso	2011	Circular	White	Red/Brown around hilum	BC	Sarconi (PZ) - Basilicata	S-Italy
NaV	Nasieddu Viola sin. Co-Mussiddu	2011	Circular	White	Violet around hilum	BC	Sarconi (PZ) - Basilicata	S-Italy

PaN	Panzaredda Nera	2011	Circular	White	Black on half grain	BC	Sarconi (PZ) - Basilicata	S-Italy
PaR	Panzaredda Rossa	2011	Kidney-shape	White	Red on half grain	BC	Sarconi (PZ) - Basilicata	S-Italy
PhC	Phaseolus coccineus	2010	Kidney-shape	White		W	Pisa (PI) - Toscana	C-Italy
PiP	Piattella pisana ^b	2004	Kidney-shape ^d	White		W	Pisa (PI) - Toscana	C-Italy
Pur	Purgatorio	2006	Circular	White		W	Colfiorito (PG) - Umbria; Gradoli (VT) - Lazio	C-Italy C-Italy
RiB	Riso Bianco	2011	Circular	White		W	Sarconi (PZ) - Basilicata	C-Italy
RiG	Riso Giallo	2011	Circular	White		W	Sarconi (PZ) - Basilicata	S-Italy
RoL	Rosso di Lucca	2004	Rectangular	Red	Black on entire grain	BC	Porcari (LU) - Toscana	C-Italy
Sal	Saluggia	2004	Kidney-shape	Cream	Violet on entire grain	BC	Salluggia (VC) - Piemonte	N-Italy
SaR	San Michele Rosso	2011	Circular	Red		MC	Sarconi (PZ) - Basilicata	S-Italy
SaM	San Michele sin. Napulitano Alto	2011	Circular	Cream	Red on entire grain	BC	Sarconi (PZ) - Basilicata	S-Italy
Sch	Schiucchiuraliedd ^{c,d}	2010	Kidney-shape	Cream	Red on entire grain	BC	Balvano (PZ) - Basilicata	S-Italy
Sci	Scicli	2007	Kidney-shape	White	Red on half grain	BC	Ragusa (RG) - Sicily	Sicily
Scr	Scritto di Lucca	2004	Rectangular	Cream	Red on entire grain	BC	Porcari (LU) - Toscana	C-Italy
Str	Stregone del Piemonte	2006	Kidney-shape	Cream	Maroon variegation on entire grain	BC	Cuneo (CN) Piemonte	N-Italy
Tab	Tabacchino sin. Fasulu Russu Nano	2011	Circular	Brown		MC	Sarconi (PZ) - Basilicata	S-Italy
Ton	Tondino	2010	Circular	White		W	Balvano (PZ) - Basilicata	S-Italy
Tri	Triverde	2010	Rectangular	White		W	Sarconi (PZ) - Basilicata	S-Italy
Tuv	Tuvagliesda	2011	Circular	White	Brown around hilum	BC	Sarconi (PZ) - Basilicata	S-Italy
TuR	Tuvagliesda Rossa	2011	Circular	White	Red on half grain	BC	Sarconi (PZ) - Basilicata	S-Italy
Vel	Vellutina di Ragusa	2006	Kidney-shape	Violet		MC	Ragusa (RG) - Sicily	Sicily
Ver	Verdolino	2011	Circular	Light green	Cream around hilum	MC	Sarconi (PZ) - Basilicata	S-Italy
Vio	Viola	2007	Circular	Brown	Black on entire grain	BC	Randazzo (CT) - Sicily	Sicily
Zol	Zolfino ^a	2004	Circular	Yellow		MC	Arezzo (AR) - Toscana	C-Italy

Supplementary Table 2 - Haralick's descriptors measured as reported in Haralick et al. (1973).

Feature	Equation
Har 1 Angular second moment	$\sum_i \sum_j p(i,j)^2$
Har 2 Contrast	$\sum_{n=0}^{N_g-1} n^2 \left\{ \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} p(i,j) \right\}, i,j = n$
Har 3 Correlation	$\frac{\sum_i \sum_j (ij) p(i,j) - \mu_x \mu_y}{\sigma_x \sigma_y}$
	where μ_x, μ_y, σ_x and σ_y are the means and the standard deviations of p_x and p_y .
Har 4 Sum of square: variance	$\sum_i \sum_j (i - \mu)^2 p(i,j)$
Har 5 Inverse difference moment	$\sum_i \sum_j \frac{1}{1 + (i-j)^2} p(i,j)$
Har 6 Sum average	$\sum_{n=2}^{2N_g} i p_{x+y}(i)$
	where x and y are the coordinates (row and column) of an entry in the co-occurrence matrix, and $p_{x+y}(i)$ is the probability of co-occurrence matrix coordinates summing to $x+y$.
Har 7 Sum variance	$\sum_{i=2}^{2N_g} (i - f_x)^2 p_{x+y}(i)$
Har 8 Sum entropy	$-\sum_{i=2}^{2N_g} p_{x+y}(i) \log\{p_{x+y}(i)\} = f_x$
Har 9 Entropy	$-\sum_i \sum_j p(i,j) \log\{p(i,j)\}$
Har 10 Difference variance	$\sum_{n=0}^{N_g-1} i^2 p_{x-y}(i)$
Har 11 Difference entropy	$-\sum_{n=0}^{N_g-1} p_{x-y}(i) \log\{p_{x-y}(i)\}$

The basis for these features is the gray-level co-occurrence matrix (G in equation 1). This matrix is square with dimension N_g , where N_g is the number of gray levels in the image. Element $[i,j]$ of the matrix is generated by counting the number of times a pixel (p) with value i is adjacent to a pixel with value j and then dividing the entire matrix by the total number of such comparisons made. Each entry is therefore considered to be the probability that a pixel with value i will be found adjacent to a pixel of value j .

$$G = \begin{bmatrix} p(1,1) & p(1,2) & \dots & p(1, N_g) \\ p(2,1) & p(2,2) & \dots & p(2, N_g) \\ \vdots & \vdots & \ddots & \vdots \\ p(N_g,1) & p(N_g,2) & \dots & p(N_g, N_g) \end{bmatrix} \quad (\text{eq. 1})$$

Supplementary Table 3 - List of morphometric features measured on seeds, excluding the mean seed weigh, the Elliptic Fourier Descriptors (EFDs) calculated according to Hâruta (2011) and the Haralick's descriptors reported in table 2.

	Feature	Description
<i>A</i>	Area	Seed area (mm ²)
<i>P</i>	Perimeter	Seed perimeter (mm)
<i>P_{conv}</i>	Convex Perimeter	Convex perimeter of the seed (mm)
<i>P_{Croft}</i>	Crofton Perimeter	Crofton perimeter of the seed (mm)
<i>P_{conv}/P_{Croft}</i>	Perimeter ratio	Ratio between convex and Crofton's perimeters
<i>D_{max}</i>	Max diameter	Maximum diameter of the seed (mm)
<i>D_{min}</i>	Min diameter	Minimum diameter of the seed (mm)
<i>D_{min}/D_{max}</i>	Feret ratio	Ratio between minimum and maximum diameters
<i>S_f</i>	Shape Factor	Seed shape descriptor = $(4 \times \pi \times \text{area})/\text{perimeter}^2$ (normalized value)
<i>R_f</i>	Roundness Factor	Seed roundness descriptor = $(4 \times \text{area})/(\pi \times \text{max diameter}^2)$ (normalized value)
<i>E_{cd}</i>	Eq. circular diameter	Diameter of a circle with equivalent area (mm)
<i>F</i>	Fiberlength	Seed length along the fiber axis
<i>C</i>	Curl degree	Ratio between <i>D_{max}</i> and <i>F</i>
<i>Conv</i>	Convexity degree	Ratio between <i>P_{Croft}</i> and <i>P</i>
<i>Sol</i>	Solidity degree	Ratio between <i>A</i> and convex area
<i>Com</i>	Compactness degree	Seed compactness descriptor = $[\sqrt{(4/\pi) A}]/D_{max}$
<i>EA_{max}</i>	Maximum ellipse axis	Maximum axis of an ellipse with equivalent area (mm)
<i>EA_{min}</i>	Minimum ellipse axis	Minimum axis of an ellipse with equivalent area (mm)
<i>R_{mean}</i>	Mean red channel	Red channel mean value of seed pixels (grey levels)
<i>R_{sd}</i>	Red std. deviation	Red channel standard deviation of seed pixels
<i>G_{mean}</i>	Mean green channel	Green channel mean value of seed pixels (grey levels)
<i>G_{sd}</i>	Green std. deviation	Green channel standard deviation of seed pixels
<i>B_{mean}</i>	Mean blue channel	Blue channel mean value of seed pixels (grey levels)
<i>B_{sd}</i>	Blue std. deviation	Blue channel standard deviation of seed pixels
<i>H_{mean}</i>	Mean hue channel	Hue channel mean value of seed pixels (grey levels)
<i>H_{sd}</i>	Hue std. deviation	Hue channel standard deviation of seed pixels
<i>L_{mean}</i>	Mean lightness ch.	Lightness channel mean value of seed pixels (grey levels)
<i>L_{sd}</i>	Lightness std. dev.	Lightness channel standard deviation of seed pixels
<i>S_{mean}</i>	Mean saturation ch.	Saturation channel mean value of seed pixels (grey levels)
<i>S_{sd}</i>	Saturation std. dev.	Saturation channel standard deviation of seed pixels
<i>D_{mean}</i>	Mean density	Density channel mean value of seed pixels (grey levels)
<i>D_{sd}</i>	Density std. deviation	Density channel standard deviation of seed pixels
<i>S</i>	Skewness	Asymmetry degree of intensity values distribution (grey levels)
<i>K</i>	Kurtosis	Peakness degree of intensity values distribution (densit. units)
<i>H</i>	Energy	Measure of the increasing intensity power (densitometric units)